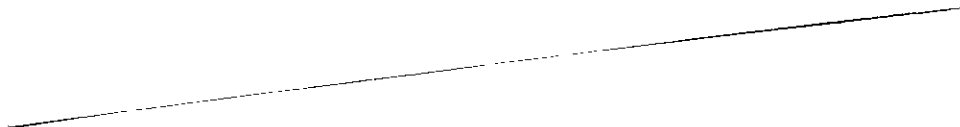


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State of California
Department of Public Works
Division of Highways
Materials and Research Department

September 29, 1964

Lab Proj. W.O. 24604-R

Mr. J. F. Jorgensen
Construction Engineer
Division of Highways
Sacramento, California

Dear Sir:

Submitted for your consideration is

REPORT OF EVALUATION

of

DISTRICT 11 CONTROL TEST PROCEDURE

for

RELATIVE COMPACTION TESTING

of

COHESIONLESS MATERIALS

Study made by Foundation Section
Under general supervision of Travis Smith
Work supervised by W. S. Maxwell
Report prepared by W. S. Maxwell

Very truly yours,

John L. Beaton
JOHN L. BEATON *JLB*
Materials and Research Engineer

cc:LRGillis:ACEstep
RRNorton:JDekema
WBCalland:PRuplinger
GEGray

Introduction

In a memorandum of March 2, 1964, to Materials and Research Engineer J. L. Beaton, Construction Engineer J. F. Jorgensen directed attention to the compaction testing of cohesionless structure backfills, and especially to a device developed by District 11 for use in such testing. This report reviews prior studies pertaining to tests in earthwork composed of cohesionless sands and gravels and discusses an evaluation of the latest District 11 approach to the problem.

Summary

District 11 includes in the Special Provisions an item directing attention to the permissive use of a specific grading limits gravel for structure backfill, and to an ASTM rodded compaction test to determine test maximum density in lieu of Test Method No. Calif. 216. Although not set forth in the item a special apparatus to determine the in-place density of the backfill is substituted for the sand volume apparatus. A steel retainer device is driven into the backfill and a density test sample of known volume is excavated from within the retainer. The findings of the evaluation of this special apparatus with a photographic record of the operation, and a discussion of methods of arriving at maximum density for relative compaction computation are reported.

Conclusions

The retainer device functioned in a satisfactory manner in both a laboratory and a field appraisal.

The District 11 policy of including in the Special Provisions a gravel structure backfill item specifying material, control test and minimum relative compaction meets with the approval of the Materials and Research Department and merits consideration by other districts.

While gravels meeting the District 11 grading limits are readily available at reasonable cost in the major construction area of the District a similar condition will not prevail in all districts. Selection of a grading within the limits of Section 19-3.06 of the Standard Specifications as dictated by local conditions will be in order.

It is recommended that the substitution of the retainer device for the sand volume apparatus be mentioned in the Special Provisions. The presence of large aggregates in the area to be tested may damage the retainer device and render invalid the test results. When it is not feasible to establish a fixed grading for the backfill which will assure satisfactory operation of the device its application may be at the discretion of the Engineer.

The nature and grading of the material will decide the appropriateness of the ASTM rodded compaction maximum density for relative compaction purposes. Test Method No. Calif. 216 is preferred when degradation is not of consequence. Fine sands are not suitable for rodded compaction. The use of the ASTM procedure may also be at the discretion of the Engineer. When the compaction control is by ASTM test a minimum 100% relative compaction specification is recommended.

Drawings and operating instructions covering the retainer device apparatus are being prepared by the Materials and Research Department.

Credit is due District 11 Materials Engineer Ruplinger for his pioneering work in the improvement of backfill placement and to Messrs. Emerson and Hartnett of his organization for the development and fabrication of the present in-place density apparatus.

Prior Investigations and Procedures

To ascertain relative compaction for construction control it is first necessary to determine the in-place density of the compacted earthwork. This is normally accomplished by excavating a test sample of the earthwork and measuring the volume of the resulting excavation with calibrated sand. In cohesionless soils and aggregates the test excavation seldom remains intact to allow sand volume measurement, i.e., the wall of the excavation caves in during the excavating or the volume measurement process. Two procedures have been employed by District 11 Materials Department to test these materials. About twenty years ago District Materials Engineer P. E. Ruplinger experimented with inserting a metal retainer in cohesionless sand and excavating a test sample from within the retainer. While this device apparently functioned in sand it was not suitable for use in gravels or gravelly materials. The concrete cylinder cans and similar thin-walled metal containers available at the time distorted on contact with gravel or rock fragments and thicker walled steel tubings created unacceptable disturbance of the test area. Some ten years later Mr. Ruplinger applied another method for testing pea gravel. A plaster-of-Paris and water mixture was introduced into the gravel, and after the mixture solidified sufficiently to cement the particles in a zone surrounding the proposed test excavation a test sample was removed from within the cemented zone.

In 1958 the Materials and Research Department conducted a study of both the metal retainer method and the cementing agent method. Steel rings 10" and 12" diameter, respectively, with a height of 3" and respective volumes of 0.1973 and 0.1379 cu. ft. were formed from well casing stock. These rings were readily inserted in uncompacted pea gravel or concrete sand, but when the material was compacted by rodding or vibration difficulty was encountered in obtaining the full 3" penetration. Considerable

disturbance of the compacted materials was observed and even the best of the test results were 2% in error. Cementing agents tried in the gravel included plaster-of-Paris and water mixture, sodium silicate-calcium chloride mixture, polyesters and paraffin liquefied with volatile solvents. While the plaster-of-Paris was found to be the most satisfactory of the various agents and acceptable for use in the gravel, the mixture failed to penetrate properly in concrete sand or Ottawa silica sand. The other cementing agents were not tried in the sands.

District 05 has on occasion employed metal retainers in cohesionless backfills. Districts 07 and 10 and Headquarters Laboratory have attempted to jack steel tubing into compacted soils of various types to obtain in-place density samples, and unreported experimental work may have been carried on elsewhere.

District 11 Backfill Control

The use of pea gravel in structure backfills has been permitted and encouraged for a number of years in District 11. Approval for use formerly granted by means of change orders has more recently been included in the Special Provisions accompanied by specific grading limits for the material. The limits currently specified are:

| | | | | | | | |
|------------|-----|--------|-------|------|-----|-----|------|
| Sieve Size | ½" | 3/8" | #4 | #8 | #16 | #30 | #200 |
| % Passing | 100 | 90-100 | 30-80 | 0-15 | 0-5 | 0-3 | 0-2 |

To avoid impact test degradation it is also stipulated that the relative compaction will be determined by the test maximum density of ASTM Test C-29-60 in lieu of Test Method No. Calif. 216. The ASTM employs a rodded procedure. A minimum relative compaction of 95% by the ASTM test required on earlier projects was raised to a minimum 100% in about 1960.

Both the plaster-of-Paris method for determining in-place density and the rodded control test received comprehensive coverage in a report by the Materials and Research Department issued in January 1962 and entitled, "Report of Laboratory Comparison of Compaction Control Tests for Pea Gravel Structure Backfills."

Development of Latest District 11 Apparatus

Cohesionless silica sand was furnished for structure backfill during 1962 on a contract near Vista. Plaster-of-Paris and water mixtures failed to penetrate the material and thin metal retainers distorted when forced into place. Mr. Harland Emerson assisted by Mr. Walter Hartnett, both of District 11 Materials Department, designed and built, for the most part in the home work shop of Mr. Hartnett, an ingenious metal retainer apparatus.

Description of Apparatus

A 7" diameter cylindrical stainless steel sleeve $6\frac{1}{2}$ " in length was formed by cutting off the bottom of a standard restaurant cooking vessel. This provided a relatively inexpensive yet durable retainer sleeve with a rounded top rim for reinforcement against distortion. A sliding hammer driving device and a sample recovery scoop designed to reach a fixed depth within the sleeve completed the apparatus.

Application of Apparatus

To determine the in-place density of a cohesionless material the steel sleeve is first worked into the material as far as can be accomplished by hand using a twisting and pushing motion. The driving device is then positioned atop the sleeve and by raising and dropping the hammer the sleeve is driven down until the top rim is flush with the surface of the surrounding material. The material within the sleeve is removed with the fixed-reach scoop to a depth which provides a $1/8$ cu. ft. sample and the weight of this sample in pounds is multiplied by 8 to compute the density. An exact hammer free-drop distance and number of blows is not critical as the sole objective is to tap down the sleeve without causing damage thereto or undue disturbance of the test area.

Evaluation of Apparatus and Procedure

While the Materials and Research Department was informed at the time the development work by Emerson and Hartnett was in progress, appraisal of the proposed procedure was deferred pending actual job applications. It has been reported the field performance has been satisfactory and the following outlined evaluation has been conducted.

Sacramento area gravel with a grading of 100% - $3/8$ ", 0% - #4 was compacted in 3 layers in a 1' high by 2' diameter circular steel mold, with each layer receiving 40 blows with a 10-lb. hammer dropping 18" to strike a 3" diameter circular tamper foot. To provide a time and labor comparison of the two procedures six trials were run using both plaster-of-Paris and the retainer sleeve side-by-side in the mold. The plaster-of-Paris method was found to be considerably more cumbersome and time consuming. If the preparation of sand for the sand volume measurement part of the plaster-of-Paris test is included, it is estimated a steel sleeve density determination requires only about $1/3$ the time required for the plaster-of-Paris operation. For this reason and also because it had been investigated and reported on in the past, the plaster-of-Paris procedure was eliminated from further consideration and additional density determinations in this gravel were made with the steel sleeve alone.

A second series of steel sleeve tests was next executed in a gravel from the Kaiser Plant at Radum which is used extensively for structure backfill in District 04. This gravel

contained finer fractions than did the Sacramento area gravel, i.e., 99% - 3/8", 49% - #4, 14% - #8, 3% - #16.

While it is probably not of consequence in testing uniform -1/2" materials, it is noted the District 11 sleeve volume of 0.125 cu. ft. fails to satisfy the 0.15 cu. ft. test hole minimum volume requirement of Test Method No. Calif. 216. To learn if a larger sleeve was practicable a 0.20 cu. ft. one was readily produced by cutting off the bottom of a larger capacity cooking vessel, and eleven trials were then run in the Kaiser gravel with each size sleeve. It was found the larger one could be handled and inserted in the gravel as readily as was the smaller one. If the procedure is adopted and presented in the Materials Manual it would appear desirable to specify a 0.15 cu. ft. volume device to avoid confliction with the standard method minimum volume.

To complete the evaluation three steel sleeve density determinations were made in a bridge abutment backfill of the Kaiser gravel on a contract in District 4. The operator was able to excavate 9 density samples and prepare 3 bulk sack samples including incidental sealing of cans and identification, but exclusive of weighings and computations, in approximately 3 hours total time.

Modification of Apparatus

When the sleeves were manipulated into the gravel a raising or fluffing of the material inside the sleeve was observed, and it was believed the base plate of the driving device came into direct contact with this material during the final stage of the driving operation. If so, some compactive effort would be applied to the test sample inside the sleeve and as the sleeve is driven down there is the possibility of packing excessive gravel into it. In addition, the time in the driving period when the sleeve rim just reaches the point where it is flush with the surface of the surrounding gravel was somewhat difficult to determine. Over-driving the sleeve places the driving device base in contact with the gravel surrounding the sleeve and delivers compactive effort thereto as well as to the sample within the sleeve. To decrease these potential hazards a circular ring of 1/2" thickness plywood was placed around the sleeve. This allows freeboard within the sleeve for the fluffed gravel, and the point at which the sleeve rim is flush with the plywood ring is discernible by the sound of wood striking wood when the driving device base contacts the ring. The reach of the sample recovery scoop was adjusted to compensate for the thickness of the ring.

A driving device with a circular base smaller in diameter than the plywood ring was constructed to permit a view of the ring while driving the sleeve. This enabled the operator to better judge the positioning of the driving device and the proximity to the ring as he neared completion of the drive. A sample recovery scoop produced to furnish a complete apparatus for the Materials and Research Department is more elaborate but not necessarily superior to the District 11 scoop. With extensive

shop services at hand in contrast to the limited facilities available to Emerson and Hartnett, refinements were readily accomplished and the suggested minor modifications are not intended as reflecting on the design or workmanship of the District 11 apparatus.

Photographic Record

The devices and operations which have been described are illustrated in the attached captioned photographs.

Discussion of Test Results

In each instance the 1' x 2' mold was filled with the gravel, the density of the gravel in the mold was computed, the steel sleeve was inserted, the sample from within the sleeve was removed and its density computed, the mold was emptied, and the full operation was repeated for the subsequent trials. For the initial three trials with the Sacramento area gravel the material was dry. In each of the remaining tests with both gravels the material was wetted.

To provide a concise summation the variation between mold densities and corresponding sleeve densities have been grouped by 0.5 lbs./cu.ft. increments and the number of test results in each increment have been shown in terms of percentage of the total number of tests. It so happened these percentages were the same for each of the two gravels so they may be combined into the following single tabulation covering a total of 28 tests representing 14 tests for each gravel:

| <u>Sleeve density variation from mold density in lbs./cu.ft.</u> | <u>Percentage of Tests</u> |
|--|--------------------------------|
| Within 1.0 | 79 |
| " 1.5 | 86 |
| " 2.0 | 93 |
| " 2.5 | 100 |

In 22 of the total 28 test instances, i.e., 79% the sleeve densities were heavier than were the corresponding mold densities; therefore, the sleeve procedure generally tends to favor the contractor rather than to impose a stricter control.

The foregoing tabulation presents the results for all determinations including those with the small sleeve alone, the large sleeve alone and the large sleeve with the plywood ring. The small sleeve alone was used for all trials in the Sacramento gravel and for the first 5 trials in the Kaiser gravel. The large sleeve was used in the remaining 9 determinations in the Kaiser gravel, but in 6 of these 9 instances the plywood ring was employed in conjunction with the sleeve. Thus, the large sleeve was tried alone only 3 times, and while the results failed to denote any superiority of the large sleeve over the smaller size, the data were too limited to be considered conclusive.

For the 6 runs utilizing the plywood ring with the large sleeve 100% of the sleeve densities were within 1.5 lbs./cu.ft. of the corresponding mold densities, in contrast to variations as high as 2.5 lbs./cu.ft. for 100% of the prior tests without the ring. It cannot be concluded on the basis of only 6 trials that all densities with the sleeve and ring will place within the 1.5 lbs./cu.ft. range of mold density, but it does appear a high percentage will do so.

Field Backfill Experience

It is not unusual for the compactive effort applied to structure backfills to be lacking in uniformity. This seems to be especially true where concrete vibrators or pneumatic hand tampers have been employed and is attributed to workmen not attaining a good coverage pattern and to insufficient applied effort. Restricted working areas often complicate, or preclude, the proper operation of more effective compacting equipment as used on embankment and subgrade work.

An investigation was conducted by the Materials and Research Department on a District 07 project in 1955. Four groups of relative compaction tests with each group consisting of 3 tests were performed in a flooded and concrete vibrator compacted clean sand backfill. The 3 tests in a given group were within an area 6' square. A range of 4% in relative compaction between the 3 tests in each group was reported. To verify the reproducibility of sand volume procedure results the in-place density of a uniformly compacted soil area on an adjacent contract was determined at eight locations. It was found that results could be reproduced.

Similar conditions have been noted in the past on other projects and again at the Kaiser Gravel backfill in District 04 which has been mentioned in this report. Three steel sleeve densities in an area which was reported to have been compacted by a concrete vibrator were 102.0, 104.6, 102.5 lbs./cu.ft. dry density, a difference from high to low of 2.6 lbs./cu.ft.

Test Maximum Density Control

Selection of an existing control test method, or the development of a new one, to derive a test maximum density for determination of relative compaction poses a problem. The effect of degradation on the test densities of gravels compacted in the impact apparatus cannot be equated. The ASTM rodded procedure eliminates significant degrading but the adequacy of even a 100% relative compaction specification based on it is questioned. Supplementing the rodding with vibration to increase the test density complicates the test for field applications, and data currently available indicate the increase in density obtained with vibration varies for different gravels.

The effectiveness of the District 11 100% ASTM control has been discussed within the district and as would be expected there is a difference of opinion between individuals. Some feel it should be raised to a 105% minimum while others believe it might be difficult to consistently attain 105% on construction. A reluctance to specify a minimum exceeding 100% by any test regardless of material or usage has been expressed on occasions of meetings with State-wide representation of materials and construction personnel.

Impact test degradation, ASTM procedure and vibration results for gravel, concrete sand and aggregate base were included in the January 1962 report already mentioned. Additional investigation during the current study was therefore restricted to the gravel of the District 04 backfill which was not involved in earlier studies. While there was some variation in the grading of test specimens both prior to and after impact compaction the following average values will serve to illustrate the degradation of this particular material:

| <u>% Passing Sieve Sizes</u> | <u>4</u> | <u>8</u> | <u>16</u> | <u>30</u> | <u>50</u> | <u>100</u> | <u>200</u> |
|------------------------------|----------|----------|-----------|-----------|-----------|------------|------------|
| Before compaction | 61 | 9 | 2 | 1 | 1 | 1 | 1 |
| After compaction | 69 | 21 | 9 | 5 | 4 | 4 | 3 |
| Increase in % passing | 8 | 12 | 7 | 4 | 3 | 3 | 2 |

When compacted in the impact apparatus the average test maximum dry density was 116 lbs./cu.ft. compared to 102 lbs./cu.ft. for the ASTM rodded compaction. The relative compaction of the uncompacted backfill area was 87% by impact control, 99% by ASTM. For the area compacted by the concrete vibrator the relative compaction was 89% by impact and 101 by ASTM.

Suggested Study of Control Densities

While the District 11 procedure may be deficient in some respects it does put the contractor on notice control testing will be in effect and encourages the use of compacting equipment. With readily compacted materials almost any effort will result in some densification and an improved backfill.

The purpose of compaction control is, of course, to provide for satisfactory performance of the completed facility, and it may be that 100% ASTM serves the purpose. A survey of backfills in District 11 placed under this control should prove enlightening.

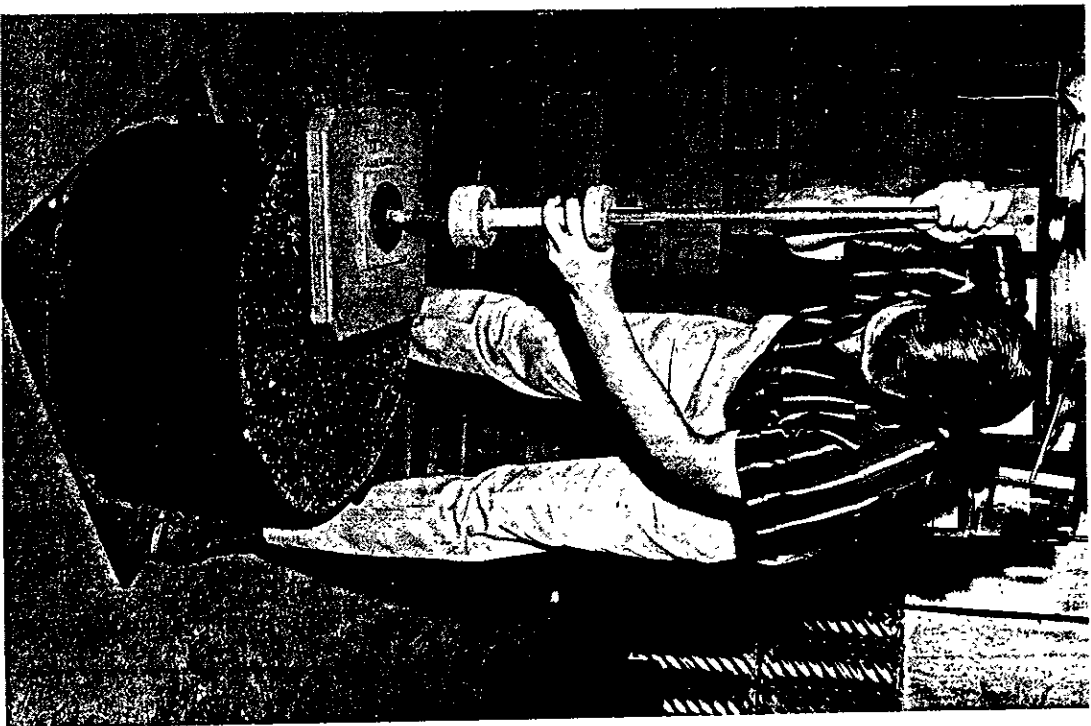
To arrive at a practical control density it is suggested that the construction of several backfills be observed by a person experienced in compaction operations and that in-place density determinations be performed concurrent with the observations. Controlled compactive effort could be provided if needed by Change Order. A relationship between actual job effort and density could thus be established. Such a study should not be as

involved nor as costly as it may at first appear. The frequent placement of cohesionless backfills suitable for testing by the means under consideration is understood to be confined to Districts 04 and 11. Similar gravels from the Radum area are used almost exclusively in District 04 and the gravels furnished in District 11 are similar between jobs in that area. In the interest of uniformity the work in both districts should be carried on by the same personnel.

To supplement the construction phase of the study the performance of the backfills under traffic could be observed periodically after the facility is placed in service.

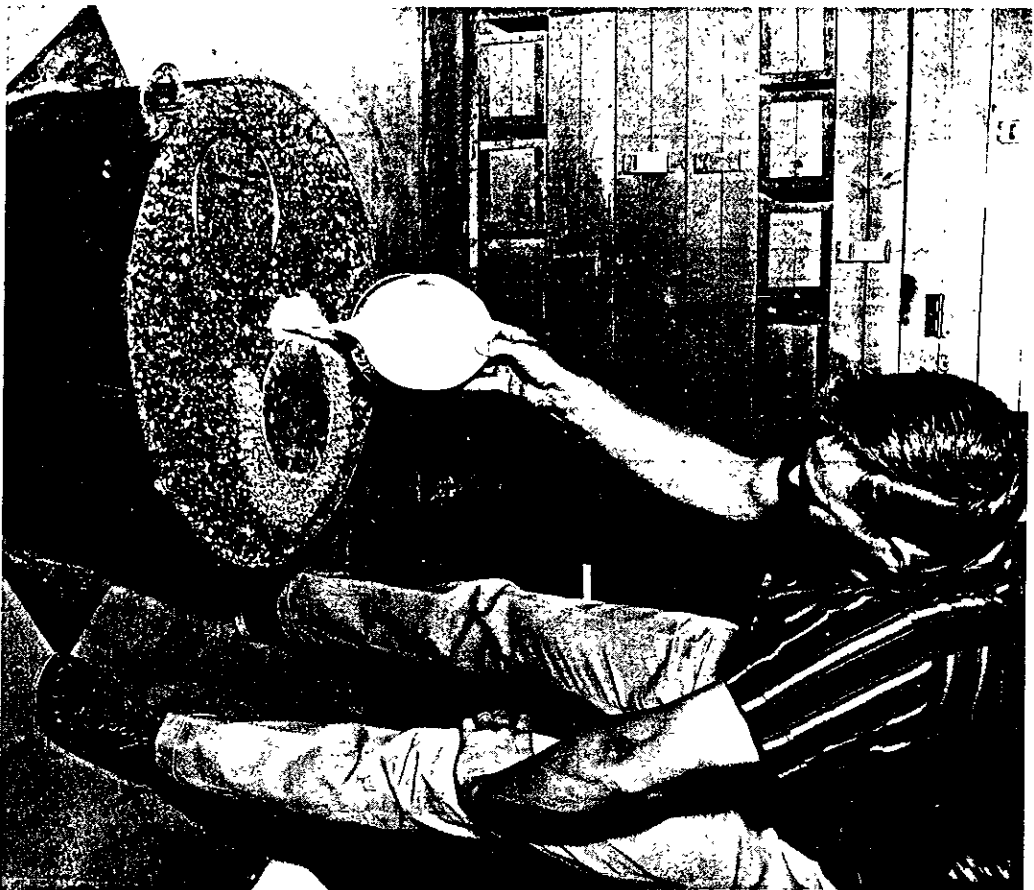


STARTING SLEEVE BY HAND MANIPULATION



DRIVING THE SLEEVE

FIG. 1



POURING PLASTER-OF-PARIS MIXTURE



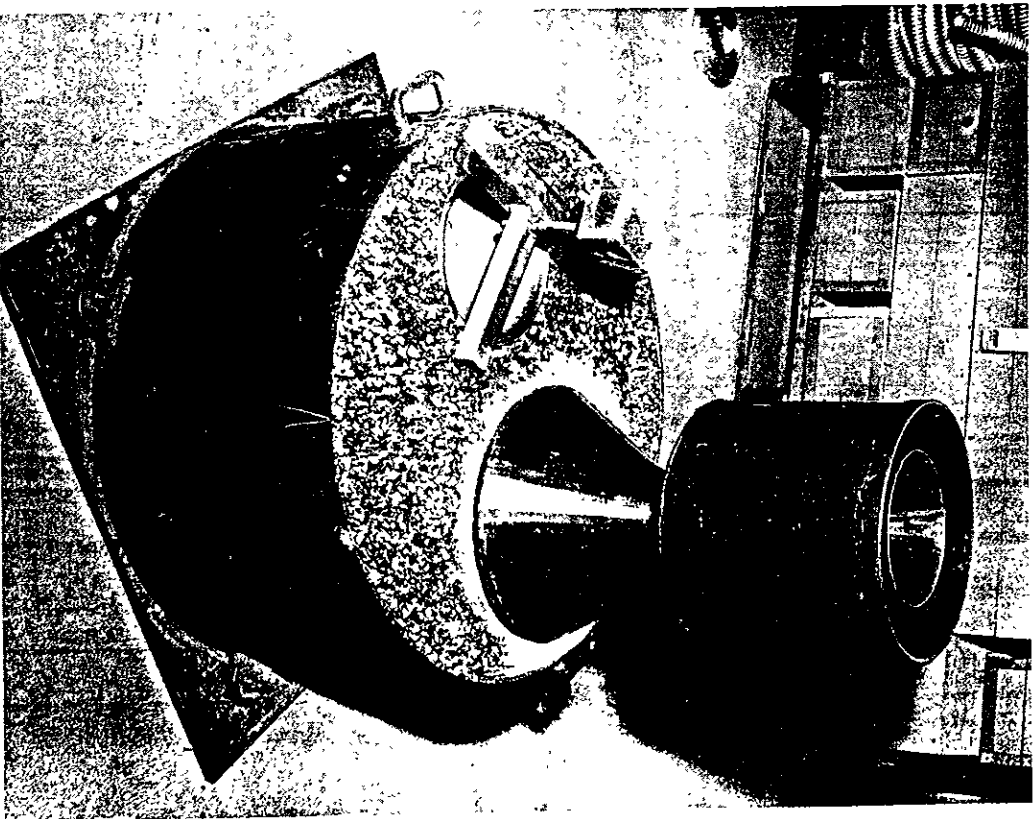
EXCAVATING SAMPLE WITH FIXED-REACH SCOOP

FIG. 11

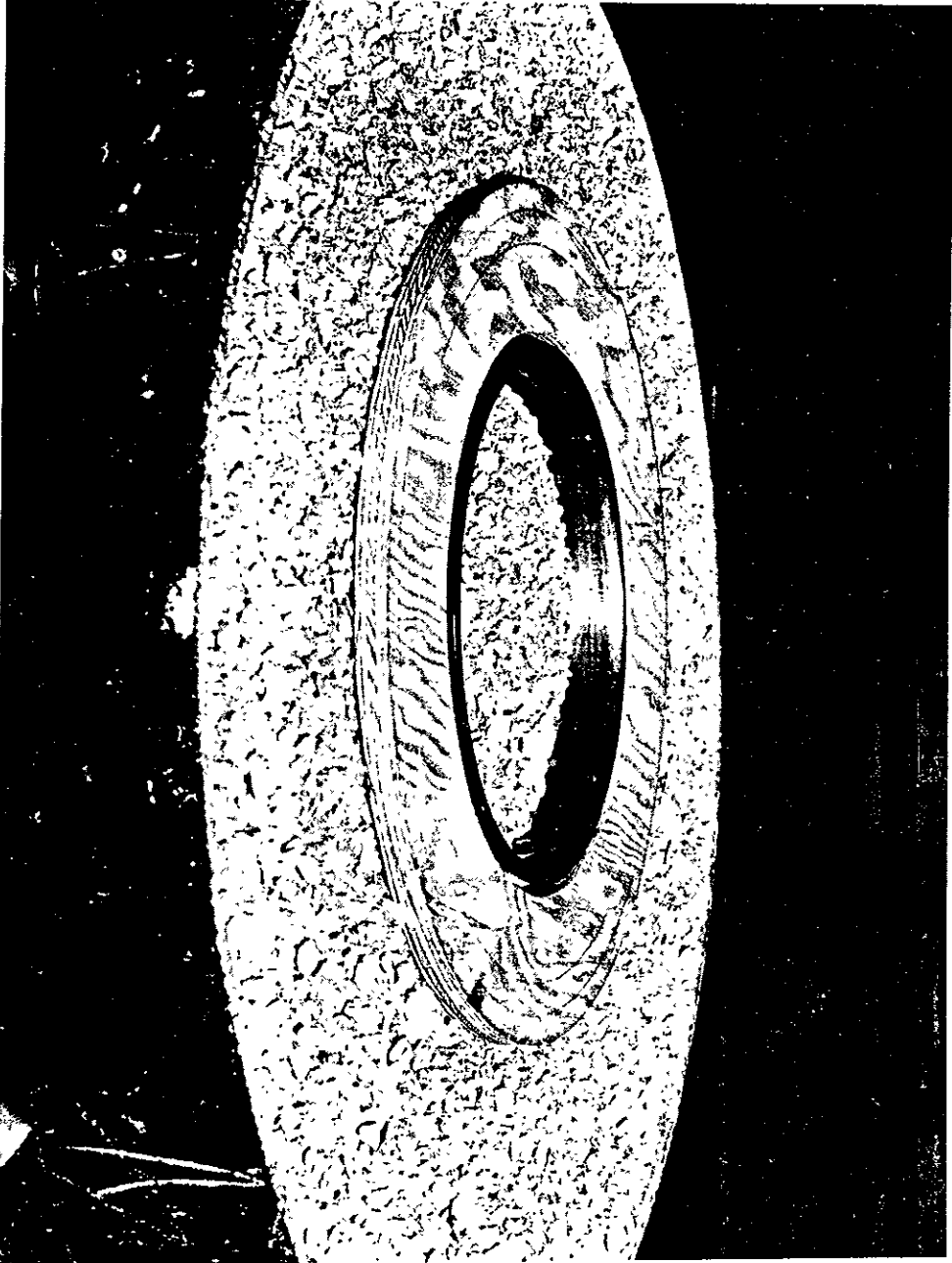


EXCAVATING TEST SAMPLE IN
PLASTER-OF-PARIS PROCEDURE

FIG. III

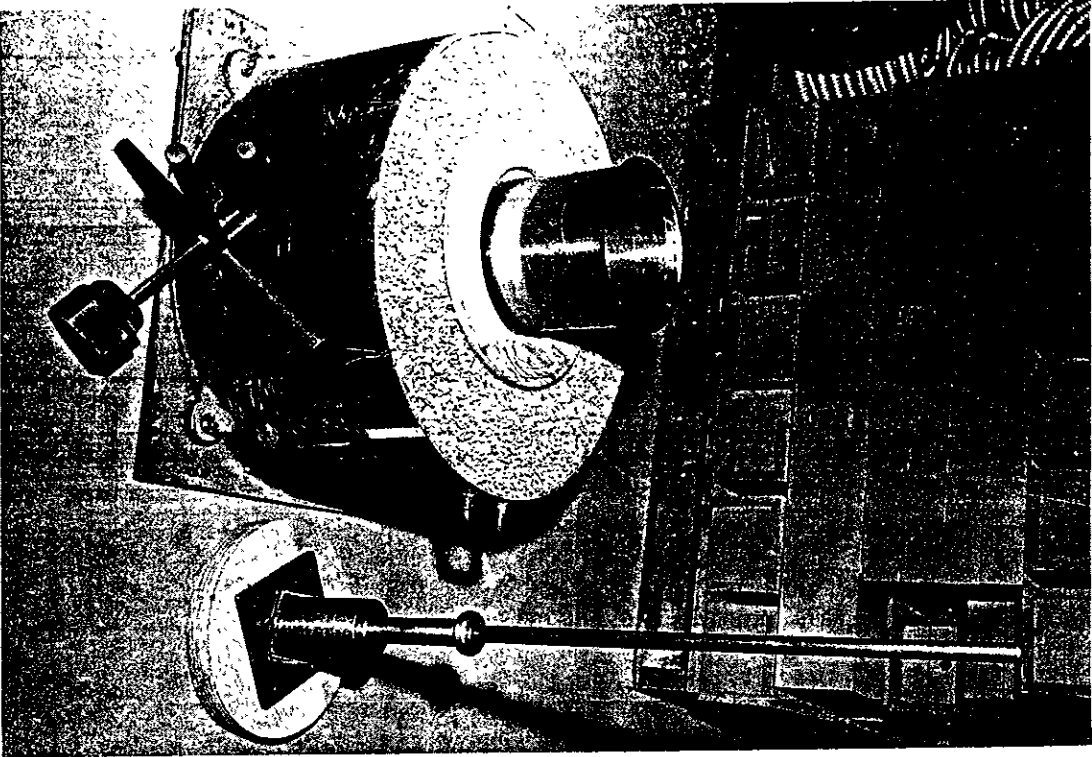


SAND VOLUME MEASUREMENT OF TEST HOLE
IN PLASTER-OF-PARIS PROCEDURE

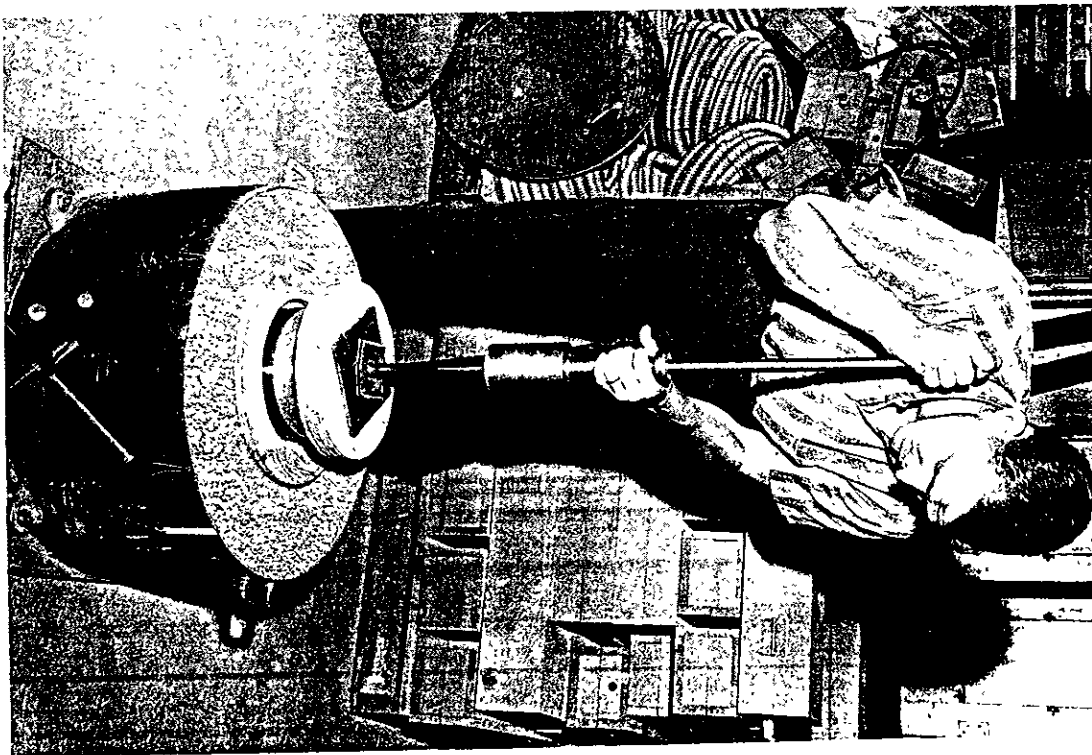


FLUFF-UP OF GRAVEL WITHIN STEEL SLEEVE. PLYWOOD RING IN-PLACE

FIG. IV



0.2 cu. ft. SLEEVE AND PLYWOOD RING



CIRCULAR BASE DRIVING DEVICE

FIG. V